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ENERGY EFFICIENCY IN COMMERCIAL BUILDINGS

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ABSTRACT

Commercial buildings form the basis or infrastructure for a hub of commercial activity and are thus a driver of economic growth. Commercial buildings require extensive heating, cooling and lighting as well as power provision for IT related items; it is unsurprising, therefore, that commercial buildings are a significant consumer of the energy or power produced. With the advent of more progressive technology, it is now possible to not only reduce the energy demand of such buildings, but it is increasingly possible to produce buildings that are energy self-sufficient, or even power producing. A move towards more efficient buildings is not without its influencing factors and its barriers; this paper reviews the current literature on energy efficient buildings with regards to energy used in a building's life cycle, the retro-fitting of buildings, an occupant's perception of energy efficient buildings, and methods of energy saving in buildings.

KEYWORDS: Energy Efficiency &Commercial Buildings

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INTRODUCTION

Buildings play a large role in the advancement and betterment of society. The main function of a building is to protect its occupants from the harsh effects of the weather and maintain a comfortable "micro-climate" whilst still allowing the more beneficial aspects of nature to reach the occupant, like sunshine and fresh air. The average person typically spends the majority of his/her life within some sort of building – an average of eight hours of sleep at night in a residential building, and a further eight hours of work/school during the day in a commercial building. As can thus be expected, the design, construction and operation of a typical building can be expected to be an energy intensive experience, with the energy used in the operations of buildings account for around 20 % of global delivered energy consumption, accounting for higher percentages in more developed countries.

In the current atmosphere of global warming and therefore encouragement towards a reduction in consumption of energy, it is important that the built environment sector in general and the building maintenance sector in particular, look towards transforming itself towards a more environmentally friendly methodology. The factors that affect this industry, and its move towards more environmentally friendly buildings, are many-fold. For example, the design of the building itself may be adapted towards using less energy for lighting and achieving comfort conditions. Legislation regarding energy efficient buildings in the area and the needs of the occupants of the buildings also has a significant effect on the energy performance of a building. The effect of a building that is built to consume less energy is far reaching, considering that the lifespan of a building is typically anything between 50 and 120 years. Thus, the energy saving methodologies used will reduce the energy needs of the building throughout its lifespan (United Nations Environmental Programme).

Types of Energy Associated with Built Environment

Primary Energy: Primary energy is defined as the energy measured at the natural resources level. It includes the extraction, transformation and distribution losses of a product and is used to produce end use energy (Qu, 2012; Ramesh et al., 2010).

End Use energy: End of use energy is the energy measured at the final use level (Qu Y, 2012).

Embodied Energy: Embodied energy is defined as the sum of all the different types of energy needed to manufacture a good. In the case of built environment, it is the measure of the amount of energy used to produce a building. It accounts for the energy used for the materials, transport of materials and the erection of the building (Thormark, 2002).

Initial Embodied Energy: Davies et al. (2014) define initial embodied energy as a sub-set of embodied energy. It is the summation of the embodied energy in all the materials used during construction. The installation of materials also forms a part of initial embodied energy.

Recurring Embodied Energy: Recurring embodied energy refers to the energy used during the maintenance phase of a building. Like initial embodied energy, it is a summation of the energy embodied in the material used during the maintenance, repair and rehabilitation of a building (Dixit, 2019; Davies et al., 2014).

Total Energy Intensity: Total energy intensity is the summation of embodied energy and operating energy (Chastas, 2017).

Buildings' Energy Requirements over the Life Cycle

Buildings require energy throughout all phases of their lifecycle. The energy is either utilized in its direct form, as with energy used during construction and rehabilitation, or through an indirect method, as with energy used in the production of the building's construction materials.

A review of literature defining "The basic life cycle of a building" has resulted in the lifecycle diagram shown in Figure 1.

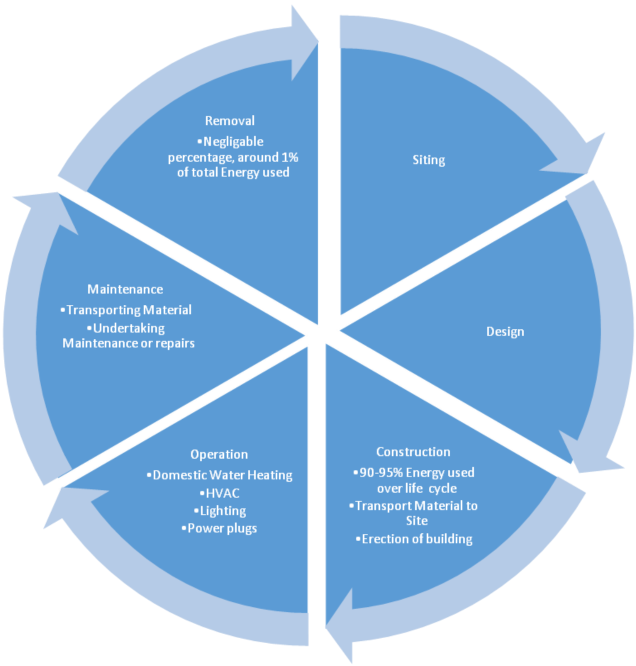

Figure 1: The basic Lifecycle of a Building

Figure 1 shows the following phases:

Siting: The siting phase consists of analysing and studying factors such as the topography of the land, the vegetation, road layouts in relation to a piece of land and factors such as any governmental restrictions with regards to the usage of the plot of land.

Design: This consist of the architectural, structural, mechanical and electrical design of the building.

Construction: Energy factors considered during this phase include energy used to produce materials, energy used to transport materials and components to the site, and the energy used during the building of the building.

Operation: The operational phase of the building life cycle is regarded as the longest phase. Operational phases typically last between 60 and 120 years and make up the majority of the lifespan of the building.

Maintenance: The maintenance period of a building runs parallel to the operating phase of the building. It is the phase in which maintenance and repair work is undertaken. Fixture and systems replacements are done during this phase. The energy used during this phase of the building is considered to be recurring embodied energy.

Operational Energy

Generally, within the literature operational energy is defined as the energy used in buildings during the operational phase for heating, cooling, ventilation, hot water, lighting and other auxiliary electrical needs (Azari, 2019:Chastas, 2017; European Committee for Standardization, 2008). Operational energy is usually the most dominant energy in buildings and has previously been found to account for around 90 % to 95 % of the energy used during the life cycle of a building. There is a virtually linear relationship between the operating energy and the total energy of a building over its life-cycle.

Factors that Affect Building Energy use during the Operational Phase

Research has found that the HVAC system within a building accounts for a large majority of the energy required during the

operational phase of the building. There is an increase in demand for thermal comfort and this has led to an intensification of energy consumption in this area.

General factors account for the energy usage within a building and affect the amount of energy needed. In general larger buildings are expected to require more energy as they generally have more occupants, and the larger surface area of the walls leads to more heat transfer within the site. This factor of surface area also accounts for the idea that the size of the rooms within the building affects the energy demands of a building. The number of occupants, and the type of activity undertaken in the building affects the energy consumption; more occupants undergoing more vigorous physical activities require a larger HVAC system to satisfy the thermal comfort demands. The severity of the weather conditions of the area affect the HVAC system sizing. In general, developed countries tend to exhibit a trend of higher energy usage within buildings, while developing countries exhibit an increased usage of energy within the environment. As per Antretta et al. (2013), the orientation of the building is also a significant factor in the energy use of a building as the heating and cooling loads in a building are affected by its orientation.

Methods of Energy Saving in Buildings

Energy use during a building life cycle is becoming a more researched science as the building industry seeks to lower its carbon footprint, and building owners seek to lower the cost of running and maintaining buildings. The rising price of energy and the recent emphasis on the effects of climate change on the population also drive the need for more energy efficient goods and industries.

Kniefel (2010) has conducted research into the energy savings, carbon emissions reduction and the feasibility of various methods of energy efficiency design in buildings by utilizing as tools the building's life cycle costing, life cycle assessments, energy simulations, emission rates and the average utility rates of the area of the building.

Kniefel (2010) has further found that in new commercial buildings, the energy use could be reduced by between 20 % and 30 % by utilizing conventional energy efficiency methods such as low-emission windows, and overhangs on windows. Energy use can be reduced by up to around 40 % for some building types, depending on the location of the building and the type of building. It was also found that the implementation of such methods were linked with increased initial cost of the building, however this initial increase in cost was mostly counterbalanced by the reduced cost on energy to run/operate the building during the life cycle of the building. It is reported in the literature that with smart, collaborative design, the initial increase can also be reduced as these designs lower the heat and/or cooling load of the building, thus reducing the need for larger heating and cooling systems and the size of the plantrooms that service the buildings heating and cooling needs, thus reducing some of the initial cost of the building. The financial benefits of reduced energy use design can also be affected by other factors such as the type of building, the local climate of the area where the building is situated and the period over which the financial analysis is done.

The type of building affects the financial benefits of energy efficient methods as different types of buildings have different design requirements. A building that is inherently larger with more occupants will require more thermal comfort systems than a building with less occupants such as a commercial office building compared to a storage warehouse for non-hazardous substances. Buildings with more vulnerable occupants or contents or in which complex operations take place, such as hospital wards and pharmacies, usually have more stringent design requirements with regards to air circulation and thermal comfort. This results in more complex HVAC systems which affect the savings made due to energy

efficient systems compared to simpler designed buildings. The location of a building also affects the life cycle analysis of energy efficient methods utilized in the building. The climate is greatly affected by the sizing of the heating and cooling systems for the building, thus affecting the benefits of the energy efficiency methods.

Kniefel (2010) found that the longer the period over which the benefits of the energy efficient methods were studied, the lower the life cycle cost of the methods and the greater the energy savings recorded.

Authors have also examined the carbon footprints of buildings. Carbon dioxide is emitted when coal is burned/combusted to produce electricity. The carbon dioxide used to produce the electricity that is utilized in the occupation of the building thus increases the carbon footprint of the building. In areas where coal combustion is the primary method of power production, research shows that an emphasis on energy efficient design can result in a lowering of the building's carbon footprint.

Kniefel (2010) found a 16 % reduction in carbon footprint across all building types over a period of 10 years. Naturally, buildings in areas with primary coal-produced power will experience a larger reduction in the carbon footprint than buildings where other types of power are utilized. It is further suggested that as the price of carbon or coal increases due to its reduction in supply, the feasibility of using energy efficient building methods increases, so the building will also cost less to operate than had no energy efficiency methods been used.

Energy Efficiency Building in Legislation

Novikova (2010) researched the link between the knowledge of energy efficiency in buildings and the implementation of this design philosophy when it comes to its adoption and policy making. It was found that energy efficiency methodology in buildings consist of two types: technological such as design and engineering use of efficient technology, and a non-technological type such as the factors pertaining to lifestyle and culture of the building's inhabitants.

The current technological approaches to building energy efficiency are maturing, well known and effective. The research states that their effectiveness can be up to 80 % in existing buildings and up to 100 % in new builds. From this, it can be concluded that the technological side of energy efficiency is not the main barrier to the move towards adopting energy efficiency methods and design. The challenge is to introduce and implement such technological approaches and designs in the global market.

There are a variety of methods or approaches to assessing and calculating the potential improvement in energy efficiency for buildings. This variety of methods, and the fact that they have differing criteria and different assumptions, further complicates the comparison of energy efficiency methods across different sections and nations.

The work of Novikova (2010) indicates that when one looks at energy consumption patterns between different populations, it is the non-technological factors (culture and lifestyle) that can account for between 10 % and 100 % of the differences between energy consumption patterns in the different populations.

Pérez-Lombard et al. (2007) recognise a distinct difference in the use of energy in buildings in developed and developing countries. They conclude that generally, energy use in buildings in developed countries is higher than energy use in developing countries, noting this may correlate to the idea that there is a higher percentage of service delivery/so-called-office-jobs in a developed country than in a developing country. Building energy use accounts for between about 20 % to 40 % of energy use in developed countries. Pérez-Lombard et al. (2007) note, however, that since energy use in

buildings is not treated as a separate sector, comprehensive data is not always available in this sector as an independent sector. In order for policies to be effectively planned for the future, building data on energy use must be made available and should be of a comprehensive nature.

Krarti (2015) researched the energy sector in the Kuwait region, examining the generating capacity of the country, along with the country's consumption patterns over a period of 20 years. Kuwait began with a mandated energy efficiency code for all new buildings in the year 1983, and in 2010 brought out an updated energy conservation code of practice. The 2010 code of practice allowed not only for new buildings, but included the retrofit of existing buildings, allowing for the use of newer energy efficient technology and a stricter code than the 1983 code. A comparison between the results of both building codes shows that the 2010 energy conservation code of practice allows for a further 23% reduction in energy usage, despite an increase in the country's population which is usually expected to greatly increase a country's energy usage. The overall finding of the study was that whilst codes for new buildings were extremely effective, they account only for new buildings. A more effective method of reducing electricity is the retrofitting of as many existing buildings as possible. In the case of Kuwait, a national retrofit of existing building stock has been found to yield higher economic and environmental benefits.

Energy Efficient Buildings and South African Legislation

The Clean Energy Solutions Centre in its publication titled *Clean Energy Ministerial* \(2016) has examined South Africa's National Energy Efficiency strategy released in 2005 with the aim of reducing energy intensity in various sectors of the country with the aim of growing the economy without growing carbon emissions as fossil fuel emission. The strategy aims to improve energy efficiency by 15 % in the commercial sector and outlines targets for industry, mining, commercial, public, residential and transport sectors. The strategy aims to guide these sectors to these targets by laying out key actions for the sectors to perform to reach the target whilst balancing this with energy security, competitiveness and economic growth.

South Africa currently has a population of almost 60 million and the majority of the country's primary energy supply comes from coal at 65.7 %, crude oil at 21.6 % and a little is attributed to gas power or renewable power sources. The South African National Energy Development Institute (SANEDI) partnered with the Clean Energy Solutions Centre (CESC) to increase energy efficiency within the infrastructure and built environment sector. The CESC research recommended the following:

- Flexible energy efficiency policy designs that allow the policy to adapt to the ever-changing market conditions. The policy can then respond to market needs and also improve over time.
- Energy efficiency programs that usually focus on the reduction of the demand should include a place for the use of renewable energy methods (that focus on the generation of clean power). This inclusion will allow support sectors in achieving their broader energy efficiency targets. Care must be taken that renewable energy programs that count under the energy efficiency program are not counted twice, once in the energy efficiency program, and again in any renewable energy programmes.
- Implementation of robust modelling tools to assess energy savings. Regarding the inclusion of monitoring and evaluation of energy savings, past usage data has generally been used as a tool to assess energy efficiency. However, the usage of modelling tools allows for a more accurate assessment of project savings, as the tools

account for changes in weather and energy demand. The use of monitoring and evaluation systems act as feedback systems and are for improving energy efficient programmes as they give insight into the energy efficiency methods that are most effective. Clean Energy Ministerial (2016) notes that the market currently lacks the capacity and practitioners to use these modelling tools and this capacity will need to be expanded in order to be effective.

Retrofitting of Existing Buildings

Chwieduk\ (2003) found that there are methods of energy conservation in both newly constructed buildings and buildings that are built and are open to retrofitting. These two methodologies are essential as the infrastructure industry is rapidly increasing. Torcellini\ et al. (2006) stated that the rate at which new buildings are constructed is generally higher than the rate at which old buildings are retired/dismantled. This is because the number of occupants of buildings is increasing.

Zhou\ et al. (2016) studied various aspect of the retro-fitting of existing buildings, where existing buildings have their existing services such as light fittings, HVAC systems and so forth, upgraded and amended to more energy efficient fittings and systems. The authors found that retro fitting of buildings may be an effective method for the implementation of green buildings. Buildings usually have a lifespan of around 50 to 120 years so it can be more cost effective to retrofit an existing building and extend its lifespan rather than tearing it down and constructing a new building.

Research in China has shown that retrofitting of a building, to enable better energy conservation, whilst still maintaining the indoor environmental quality according to the occupiers' demands (where occupants can still adjust temperatures according to their comfort after the retrofit), can allow for up to 57 % reduction in energy consumption compared to similar buildings in the country.

Krarti (2015) researched the retrofitting of buildings and development of energy efficiency codes in Kuwait, and proposed the following recommendations:

- That the programme begins by gradually implementing a mandatory energy efficiency retrofit programme, beginning in the residential sector and thereafter being adopted by other building sectors.
- The energy conservation code of practice to be updated regularly (every 5 years) to account for the new technology available and to slowly introduce more stringent/stricter codes for buildings.
- In areas where a water and power subsidy is given, these subsidies to be reduced progressively. A grant can be simultaneously given to aid in the retrofit of the building. This will encourage building owners to retrofit, or to save on the usage of water and power.

Energy Efficient Buildings, Operational Strategies and the End User Experience

Hauge et al. (2010) investigated user experience in buildings that are energy efficient. User experience is an important factor as the end user is in fact the body utilising the building, and their comfort levels, safety and convenience are vital factors in the design of any building. Research has looked at energy efficient buildings of varying types in terms of comfort levels, occupants’ attitudes and satisfaction of the user. It was found that the quality of green buildings often differs, and this results in differences in user experience. Research indicates that misunderstandings regarding how energy efficient buildings operate and the appropriate maintenance steps required can result in a less than optimal experience and could result in an unsatisfactory user experience. In order for the occupant to have a positive building experience, the user should

have appropriate information on the operation of the building, and the user should feel in control of their comfort level such as the temperature of the room. Some researchers state that the social context in which user experience is evaluated still requires further research. User experience may be coloured by factors such as their experience whilst moving into the building, out of a previously familiar building and the users' knowledge of environmental issues. It is also suggested that it would be beneficial to familiarise building occupants with information and basic training related to the building's energy efficiency methods.

Hauge et al. (2010) found two slightly differing opinions with regards to users perceived comfort levels in energy efficient buildings: on the one hand users often feel more comfortable, have an increased level of wellbeing, and have better work performance in green buildings, but on the other hand, often no differences are found in users perceived comfort between energy efficient and conventional buildings. Some researchers state that users tend to have a higher tolerance to deficiencies in buildings when they are aware that the building is energy efficient compared to conventional buildings and further surmise that this indicates that the "image" of the building as a green building influences the occupants' perception of the building.

A further influence on the building's occupants' perception could be the fact that the building is an entirely new building. This could lead to the occupants feeling valued by their company, that they are worthy of a new building, or, on the contrary, feeling unhappy as it is a new building and they are unfamiliar with it. Employees' relationship with the company, company leaders and so forth also affect their perception of the building and may affect the perceived comfort of the building.

Occupants' perception of energy efficient buildings in the residential building market are similarly complex. Residents who perceived themselves to be environmentally conscious are those who give importance to the environmental aspects of houses, and those residents are usually few. The norms of society also affect the residents' perception; purchasing passive or environmentally friendly houses is against the norm and can be considered an 'extreme' approach, with many residents choosing to identify themselves as within the norm and not having any extreme inclinations. Residents who choose energy efficient or passive buildings may also feel as if they have to explain or justify their choice to their peers.

A number of authors have emphasized that much of the design process of an energy efficient building lies in the architectural processes, such as building orientation, use of materials, daylight, window area and placements and the general layout. These are also the choices that directly affect the user of the building. This relationship will affect the user's perception of the building and when both user comfort, and energy efficient design are balanced, will result in a positive perception from the user.

Research has also shown that there exists a relationship between energy saving methods enveloped into a building's design (such as passive architecture and a building envelope that reduces the demand for heating and cooling), and the building management that occurs during the operational stage of the building. An effective operational strategy is one where occupants are aware of the energy savings and/or energy generation methods of the building and are able to adjust settings and temperature levels to suit their needs. Research has shown that it is also possible to implement conventional energy savings coupled with effective operational strategies, to decrease energy use, especially of it is not possible to implement renewable energy methods in the building.

Gaps in Research

The research finds that a gap exists between the simulations used to design the energy efficient buildings and the actual indoor climate experience of the building. The bridging of this gap will further help in refining energy efficiency design processes. The relationship between technological potential savings, and non-technological potential savings is not widely researched and is not thoroughly understood. Technological energy efficiency methods are generally more widely understood and researched than non-technological energy efficiency methods.

In order to adopt common energy efficient building design, the barriers to entry need to be researched. Scholars have stated that that the existing research serves to identify some of the barriers, but does not elaborate them sufficiently. It states that it would be highly advantageous if these barriers were ranked, their importance quantified, and the effect of the barriers understood by key policy makers, in order to implement the adoption of energy efficient building methods.

The literature indicates that more information should be collected on the energy demand side in order to analyse the trends in energy demand. This will further enable policy makers to decide on which energy demand sectors to prioritize and focus on.

Killip et al. (2019), who are researchers from the Environmental Change Institute University of Oxford, examined the multiple benefits of energy efficiency in terms of how they affect individual businesses. Their research indicates that more research needs to be directed towards the multiple benefits of energy efficiency for businesses. Some of the non-energy related benefits include a reduction in production down-time, improved productivity in businesses, and, possibly, an increase in product quality. Some scholars show that these factors are usually non-quantifiable or at least not easily quantified and are therefore less researched and less reported on. The little research that is available on these benefits currently places them under the cost-benefit analysis of the business in order only to increase the scope of the cost benefit analysis. It has been found that as it stands, energy efficiency and energy payback are not usually high priority aspects for decision makers in businesses, and when looked at, energy efficiency is integrated where it can fit into other decision-making factors. Due to this, there is little research and work done in terms of making or adopting an approach where energy efficiency is a prominent approach to business decisions.

Pérez-Lombard et al. (2007) concur that that building energy use is not commonly reported on as its own independent sector. Chastas (2017) states that such data needs to be collected and reported on in a comprehensive manner in order for governments to come up with effective policies regarding building energy use.

Of the various buildings whose energy use patterns have been established or researched, before and/or after retrofitting, it has been found that the majority of the buildings were located in European countries. China also researches their buildings energy patterns as do some Arab regions. It was also found that the European, Chinese and Arabian studies are often slightly older more than 20 years. This suggests that the field of building energy use is fairly established in those areas. In contrast, the research into building energy use and the improvement in energy efficiency in the African context is not as widely studied or researched and is a gap in knowledge that urgently needs to be filled.

CONCLUSIONS

Energy use and energy efficiency in buildings is a growing research field. Even though it is not a field in its infancy, energy use in buildings is a vast research field due to the many factors that affect the field. These can include factors such

as the political climate, legislation regarding buildings, availability of materials and technologies for building and the variation of building standards practices and codes between countries. Another factor is the building occupants' expectations regarding building services such as hot water, air conditioning and lighting. The research suggests that more studies into commercial buildings such as office buildings or government buildings, their energy use patterns, and energy demands by occupants, is warranted. This author has found that whilst there are studies in commercial buildings in many European and Arab areas, the study of energy in buildings in African countries are far fewer and much less widespread. There is a pressing need to further quantify the energy used in commercial buildings in Africa, particularly in Southern Africa, as these areas experience intense solar radiation which affects the HVAC systems of all buildings and further affects buildings' energy use patterns.

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